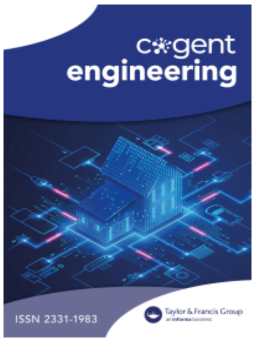

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Fabrication and investigation of local clay-based insulators for high voltage applications

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ABSTRACT
Nigeria has a large deposit of clay which is the major raw material for the fabrication of porcelain insulators for high voltage applications. However, the country depends largely on imported porcelain insulators to meet its high voltage needs even in the face of the worsening exchange rate of the Nigerian currency compared to the US dollar and other foreign currencies. As a result, it becomes necessary to sort for local means of fabricating high voltage pin insulators from locally available raw materials. In this study, clay sourced from three different geographical locations (Auchi, Ikorodu, and Ota) are used to fabricate three samples of high voltage insulators. The fourth sample of insulator is also fabricated from the Ota clay with Plaster of Paris (POP) as an additive to enhance workability. The physical and electrical properties of the insulator samples are investigated and compared with imported porcelain insulators. The results show that the insulator fabricated using the clay from Auchi has the highest breakdown voltage of 5 kV and lowest leakage current of 2 mA and thus can be adopted for low-tension insulation instead of the high-tension insulation speculated from the onset of the research.

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1. Introduction

There are increasing applications of high voltage systems both in the industries, laboratories and in everyday life as a result of modern civilization and industrialization (Kim et al., 2020). The application of high voltage is more pronounced in power transmission systems as power is often transferred over long distances at high voltages to minimize I^2R losses (Sadovskaia et al., 2019). Any alternating current (AC) voltage above 1 kV or direct current (DC) voltage above 1.5 kV is adjudged to be high (Yaabari et al., 2021).

The use of such high voltages is associated with the dangers of electrocution including irregular heartbeat (arrhythmias), thermal burns, localized death of cells (myonecrosis), and death, among others (Goyal et al., 2020)-(Nizhu et al., 2020). Poor insulation has the potential of damaging power system equipment and causing injury to personnel (Wang & Qiu, 2019). As a result, good insulation is required for high voltage systems, in which porcelain-based materials are used (Ayode Otitoju et al., 2020). The major compositions of porcelain insulators are ceramics and additives such as barium titanate ($BaTiO_3$) (Mehta et al., 2021), glass waste, Zinc Oxide (ZnO)(Taghvaei et al., 2021), etc.

Clay which is a naturally occurring ceramic is obtainable in varying quantities all over the world (Jeremiah et al., 2020)-(Otunola & Ololade, 2020). It is available in every part of Nigeria in large quantities (Adamu & Duru, 2020)-(Chiadighikaobi & Tarka, 2021). However, its potential application in the fabrication of porcelain insulators for high voltage insulation seems untapped. Despite the large deposit of clay in Nigeria, the country still depends on imported porcelain insulators to meet its high voltage insulation needs (Mgbemere et al., 2019) (Ekpunobi et al., 2021).

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In the face of the worsening exchange rate of the Nigerian currency compared to the US dollar and other foreign currencies, it becomes necessary to develop means of cutting down the importation of essential materials such as porcelain insulators. It is in the light of the above that this study fabricates and investigates the properties of insulators fabricated using clay as the local raw material to ascertain their suitability for high voltage applications.

Several studies on the fabrication and investigation of porcelain insulators from local material have been carried out by researchers recently. In (Rady & Desouky, 2021) porcelain insulators were fabricated from raw materials (majorly, clay) available in Egypt using conventional ceramic methods with different proportions of SnO_2 as additives, and samples were investigated. The insulators were treated at varying temperatures ranging from 900 °C to 1200 °C. The results showed improvement in the dielectric properties as the percentage of SnO_2 additive increased. Thus, porcelain insulators made from local materials (clay) with SnO_2 have useful features for several technological applications.

Similarly, the authors in Onu and Big-Alabo (2020) experimentally characterized a clay-based locally fabricated porcelain insulator for 415 V applications using a Hipotronic dielectric AC test set. The result showed the fabricated insulator to have a resistance of 8.33 x $10^6\,\Omega$, dielectric Breakdown strength of 4.6 x 10 4 V/m, and dielectric withstand Strength of 3.8 x 10^4 V/m. In the same vein, Ezenwabude and Madueme (Ezenwabude & Madueme, 2015) produced and investigated the properties of samples of porcelain insulators from fine clay, stoneware clay, quartz, and feldspar. From their investigations, the water retention ability, porosity, and bulk density of the sample with the composition: 20% feldspar, 30% quartz, and 50% stoneware were found to be 14.44%, 25.23%, and 1.75 g/cm^3 respectively at 1200 ^{0}C. The breakdown voltage of the sample was also found to be 45 V/m. Such results showed that locally sourced materials could be used to produce porcelain insulators of high quality.

More so, the authors in Merga et al. (2019) studied the properties of 5 samples of porcelain insulators fabricated from raw materials of Ethiopian origin (kaolin, quartz, and feldspar) mixed in different proportions. The samples were heated to high temperatures between 1000 to 1300 ^{0}C. The properties of the samples (including water retention ability, porosity, dielectric strength, bulk density, and microstructure) were tested. The test result showed that the sample mixed with feldspar, kaolin, and quartz in the ratio 4.5: 4.5: 1, was found to exhibit superior properties for fabricating standard porcelain insulators.

A review on the use of local raw materials (kaolin, quartz/silica, and feldspar) obtainable in developing countries for the fabrication of porcelain insulators was carried out by the authors in Ekpunobi et al. (2021). The raw materials were investigated in different percentage compositions by weight. Results showed that the water absorption, insulation resistance, porosity, bulk density, and dielectric strength of the insulators were relatively acceptable indicating that local raw materials in the developing countries can be used to produce high-quality insulators. In (Belhouchet et al., 2019), the fabrication of porcelain insulators from locally sourced materials (mixture of quartz, kaolin feldspar, and recycled glass wastes) and the effect of glass waste additive on the physical properties of porcelain insulators was investigated and presented. The results revealed dielectric properties enhancement due to the glass waste additive. Also, a phase angle of approximately -89.2°C was obtained for the porcelain. The results portrayed the developed porcelain as a good insulator.

In addition, the authors in El-Mehalawy et al. (2021) fabricated and investigated the dielectric properties of self-glazed porcelain insulators made from kaolin and natural rhyodacite sintered at different temperatures. The sintering at dissimilar temperatures was done to determine the verification ranges and best sintering temperature. The fabricated materials were found to have low dissipation factors with stable dielectric constants at high frequencies. The materials can thus be used in high voltage systems that operate at high speed.

Literature has shown that a lot of work has been done on the fabrication and investigation of the properties of porcelain insulators from local raw materials to ascertain their suitability for high voltage applications. However, the comparative analysis of the properties of insulators fabricated from local clay materials from different locations within a given entity (country) seems unexplored. Thus, in this study, a comparative analysis of the properties of pin insulators fabricated from clay samples obtained from three different States in Nigeria (Lagos, Edo, and Ogun) was carried out to be able to identify a possible location of clay deposit that will be suitable for high voltage insulator materials sourcing. The effect of using POP as an additive (to enhance beauty and workability) on the properties of porcelain insulators was also investigated.

2. Processing and preparation of samples

This section discusses in detail how the clay insulators were produced using different clay samples. The imported porcelain insulator was used as a model to produce the clay insulators.

2.1. Sourcing of clay samples

Clay soil exists in large quantities in Nigeria as almost every part of the country has a significant share of it (Akpomie et al., 2019)-(Ihekweme et al., 2020). However, the physical properties (color, texture water retaining ability, and workability) and chemical compositions of the clay vary from one location to the other (Lydia et al., 2019). The clay samples whose high voltage insulation properties were investigated in this study were sourced from three locations in Lagos, Edo, and Ogun states in southwestern Nigeria. The physical attributes observed in them are shown in Table 1.

2.2. Production process

Four steps are involved in the process of producing the clay insulators. These steps include the purification of the clay samples, formation of the clay samples into a 33-kV insulators shape, bisque firing, and glazing

2.2.1. Purification of the clay samples

The clay dug contained impurities that must be removed before use. The following procedures were followed for the removal of impurities for the three samples.

1. The three clay samples were dropped into different pails of water without stirring to avoid the trapping of air that can aid porosity and achieve good slaking.
2. The clay was left in the pail for 5 days. After 5 days it was realized that the clay had settled and turned to paste.
3. Extra water was removed from the top of the clay.
4. A sieve was used to filter the impurities from the clay
5. The clean clay paste was spread evenly on a clean concrete floor to lose water to the point when it was thick enough to be formed into shapes.
6. The impurity-free clay was kneaded properly and stored in an airtight plastic bag to avoid further hardening of clay before use.

2.2.2. Formation of the clay samples into a 33-kV insulator and glazing

A commercially available 33-kV porcelain insulator (Figure 1) was purchased and the dimensions were obtained. The sectioning of the electrical porcelain insulator (Figure 2a & b) was used as a guide to producing the clay insulators. The drawing was followed to get the shape and dimensions.

This was done by kneading the clay and forming the shape with the hands. After the shape was achieved, the wet clay insulator was placed on a table to dry at room temperature of 27 °C.

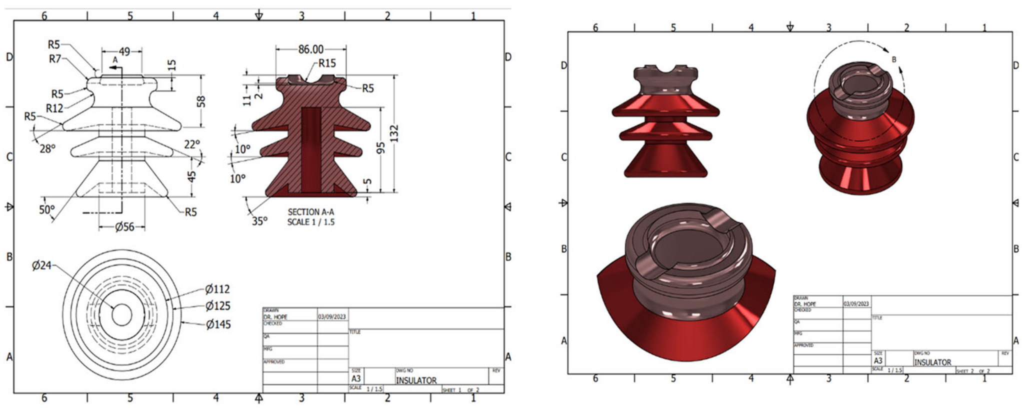
Three clay insulators were produced from the samples gotten at the multipurpose laboratory in the Department of Electrical and Information Engineering of Covenant University, Ota, Nigeria. Each clay insulator represents the different sources of the clay samples i.e. Ikorodu, Ota, and Auchi. All the three insulators were made with clay with no additive. Figure 3a–c shows the three insulators that were molded from the clay samples.

A fourth clay insulator was made with Ota clay. This forth clay insulator contained an addictive called POP. 10% POP was added to the clay to enhance its workability as seen as it has a better physical resemblance to the target shape (Figure 3d). The POP was added to a small quantity of water to achieve a paste. This POP paste was mixed with the clay to be

Figure 1. A commercially available 33-kV porcelain insulator.

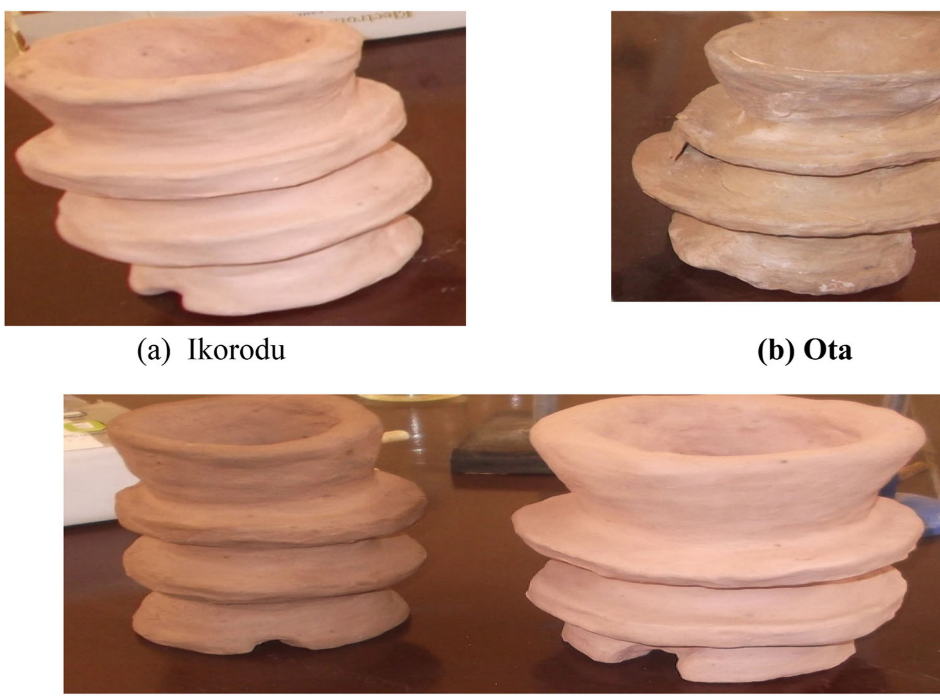
Table 1. Physical observations of the clay samples.

S/N	Location	Colourof clay	Texture of clay	Water retaining ability	Workability
1.	Ikorodu	Light Brown	Very smooth and fine	High	Easy to work on
2.	Ota	Orange-Red	Fine	Low	Difficult to work on
3.	Auchi	Dark Brown	Fine	Medium	Medium



(a) (b)

Figure 2. (a) The drawing of the 33-kV electrical porcelain insulator showing dimensions. (b) The drawing of the 33-kV electrical porcelain showing the shape as determined by the dimensions of the drawing.



(a) Ikorodu **(b) Ota**

(c) Auchi (d) Ota with POP additive

Figure 3. The clay-molded insulators.

used and the clay insulator was shaped out. It was left to dry at room temperature on a table.

2.2.3. Bisque firing of the clay insulators

The clay insulators were weighed and bisque fired in an oven at the end of the 7th week. They were put in the oven and the temperature was increased gradually from 115 °C to 250 °C. The temperature was increased hourly till it reached 250 °C. The clay insulators were heated for 6 hours after which the oven was turned off and allowed to cool inside the oven. Thereafter, the clay insulators were weighed again.

2.2.4. Glazing

A velvet underglaze was applied to the body of the clay insulator. This gave it the appearance of velour or velvet. Figure 4a shows the appearance of the clay insulators after applying the glaze. Thereafter a gloss varnish was applied to the bodies of the clay insulators to give them a glossy finish and make them waterproof. The application of this gloss intensified the colour that the velvet underglaze gave it initially. Figure 4b shows its appearance with the application of the gloss.

3. Observations, tests, results, and discussion

In this section, the physical changes in the insulators as well as their electrical characteristics are presented.

3.1. Physical observations

3.1.1. Physical observation before glazing and glossing

The Ikorodu clay sample was observed to have some cracks on its body. All other samples were still intact and had no cracks on them.

3.1.2. Physical observation after glazing and glossing

It was observed that the application of the velvet underglaze did not give the insulators a glossy finish as shown in the sample in Figure 4. All samples came out well except for the sample with 10% POP on which cracks were observed on the glazed body. It was noticed that with the application of the gloss finish, the previous colour on the clay bodies intensified and also gave it a perfect finish as shown in Figure 4b.

3.1.3. Weight analysis

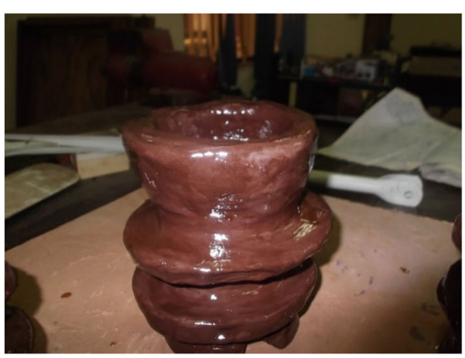
The clay insulators were weighed constantly till there was no change in weight. Table 2 summarizes the results.

The weights in Table 2 were the weights of insulators before bisque firing which was carried out after the seventh week. The table showed that with POP additive, the weight of the Ota clay insulator was reduced by 12.53% The weights of the bisque fired insulators are shown in Table 3.

Tables 2 showed a uniform change in the weights of the insulators irrespective of the source of clay used while Table 3 showed that after bisque-firing the overall weight of the clay insulators shrunk by approximately 4 to 10%.

3.2. Electrical tests, results, and discussion

According to the British Standard Three different tests are normally carried out on an insulator to determine its electrical applications. These tests include: the Dry Dielectric, Wet or Rain Flashover (done at required voltage and frequency) and



(a)

(b)

Figure 4. Sample of the clay insulator after. (a) Applying the glaze. (b) The application of gloss.

Table 2. Weight analysis of the molded clay insulators.

	Weight in grams (g)			
Interval after its production (Week)	Ota Clay	Ikorodu Clay	Auchi Clay	Ota Clay With 10% POP
1	2200	1570	1600	1900
2	2160	1549	1580	1850
3	2115	1510	1576	1840
4	2104	1504	1573	1838
5	2100	1503	1572	1837
6	2099	1502	1571	1836
7	2099	1502	1571	1836

Table 3. Weights before and after Bisque Firing.

Clay sample	Before bisque firing (g)	After bisque firing (g)	Change in weight (g)	% Change in weight (g)
Ota Clay With 10% Pop (Insulator 1)	1836	1820	16	0.88
Ota (Insulator 2)	2099	2094	5	0.24
Auchi (Insulator 3)	1571	1544	27	1.75
Ikorodu (Insulator 4)	1502	1440	62	4.31

Figure 5. The test bed used for the insulation testing using Megger S1-1568 15 kV insulation tester.

impulse voltage tests. In Dry Dielectric Test, the insulator specimen to be tested is mounted in such a manner in which it would be used practically. Then the applied supply is varied gradually from zero up to the specified value and held for at least one minute. The voltage it must withstand must be less than what it is to be used for.

The next is the wet test. This is caried out like the dry test, but the insulator sprinkled with water just like rain. The expected voltage is maintained for one minute and observe that there should not be any flash-over.

The final test is the insulator performance test. Here, properties like mechanical strength, porosity, puncture voltage, corrosion as well as temperature cycle are assessed.

In this work, however, only the dielectric dry test was carried out according to ANSI/NEMA C29.1-1988 (R2012) Insulators Test Method in the high voltage laboratory in the university of Lagos as well as using Megger S1-1568 15 kV insulation tester. Figure 5 shows the test bed used for the insulation testing.

Dielectric tests were carried out on all the clay insulator samples at the High Voltage Laboratory of the University of Lagos, Nigeria, except the Ikorodu clay insulator which had so many cracks and defects in its body. The following results were obtained after the completion of the dielectric tests on the clay insulators. Two different 11 KV porcelain insulators (Insulator 1 and insulator 2) were used for the control tests. The results of the dielectric tests are shown in the Table 4. The test conditions were room temperature: 27.3 °C and Humidity: 95%.

From Table 4, Auchi gave the best electrical characteristics. It withstood a voltage of 5 kV. It also had the least leakage current which means it was safe to touch. It can withstand LT (Low Tension) insulator based on the test result.

4. Conclusions

Pin insulators were produced using the clay samples gotten from the different locations as an alternative to imported porcelain insulators. The clay molding of the insulators was done in the Electrical and Information department of Covenant University, Ota, Ogun State, Nigeria. They were dried at room temperature (27 °C) and it was bisque-fired in an oven at a temperature of 250 °C. Glaze and gloss were applied to its body to give it a perfect finish. Dielectric dry test was carried out on the insulators at the University of Lagos high Voltage laboratory and using portable Megger S1-1568 tester to know the withstand voltage, breakdown voltage, and leakage current. From physical and electrical assessment, the insulator made from the clay obtained from Auchi gave the best result. It withstood a breakdown voltage of 5 kV and had the least leakage current which means it was safe to touch. It can withstand LT (Low Tension) insulator based on the test result. With the completion of this investigation, it is revealed that using clay as an insulating material to produce high voltage insulators is feasible. Since it is widespread and available in most states in Nigeria, especially in the riverine areas, its exploration will also save the country from expending foreign

Table 4. Dielectric tests results of clay insulator samples.

Insulator samples	Inception voltage (kV)	Withstand voltage (kV)	Breakdown voltage (kV)	Leakage current (mA)
Ota	4	2	8	2.2
Auchi	6	5	8	2.0
Ota With POP	6	4	8	2.2
Insulator 1 (Imported	60	56	68	2.2
Insulator 2 (Imported)	52	52	62	0.9

exchange on importing porcelain insulators. Furthermore, no complicated machinery is needed to mold the clay into shapes for the insulation area to be insulated. However, for commercial production, special die and sand casting can be produced for getting the required shape. An inexpensive kiln can be made also for firing the clay. This will also reduce the cost of manufacturing the insulators.

Further works shall investigate the wet test and performance test properties of insulators fabricated from clay obtained from the same three locations and POP additive, but bisque fired at higher temperatures. The microstructure of the samples and implications on the insulation properties will also be investigated.

Disclosure statement

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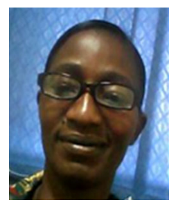

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